Agricultural Waste Management in Europe, with an Emphasis on Anaerobic Digestion

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Abstract

Traditionally, animal residues such as solid and liquid manures of cattle, pigs and chickens, have been used for fertilization purposes. However, with the onset of the industrialization of agriculture, animal production has become more and more centralized, and there is too little land for the application of such wastes within a short distance of the sources. Therefore, treatment technologies like the separation of the liquid and solid fractions of manures, their drying and composting have become popular.

Most recently, in response to climate and fuel crises, anaerobic digestion has been advocated and supported by political measures in many European countries. In 2010, the European Union made the commitment to reduce greenhouse gas emissions by 20% before 2020. Amongst other approaches, biomethane production from agricultural wastes has been proposed. In Germany alone, more than 7000 biogas plants are now in operation, and other countries in Europe are starting to follow this trend. Engineers and foremost microbiologists are constantly challenging to improve the technology in this field. Recent advances in microbiological and molecular techniques have made it possible to determine which microorganisms are present in the anaerobic digester environment, how active the microbes are, and how the microbial community as a whole responds to changes in substrate input and process conditions.

This paper gives a few examples of biomethanisation studies that have been carried out at the Institute of Microbiology in Innsbruck. There and elsewhere, Microbial Resource Management, a new attractive field for microbiologists, should help to mitigate climate change and to close biogeochemical cycles for a more sustainable future society.

Introduction

In the last few years, environmental policy in Europe has been reacting to various drivers in the energy sector. First of all, the notion was that non-renewable energy sources like natural gas and crude oil are limited, and that the world would soon be facing Peak oil. This upcoming shortfall in resources resulted in the soaring oil prices. Furthermore, political troubles showed that the dependency on the Middle East and Russia for oil and gas, respectively, was rising. Nuclear energy, which has been treated as a feasible alternative, is unpopular in many countries, and has become even more so after the Fukushima disaster. Renewable energies have thus been demanded by the people, and politics has responded adequately by heavily subsidizing research and application of energy sources including photovoltaics, wind, and biomass. Figure 1 summarizes the current situation for various European countries.

However, all these technologies have not remained undisputed. This mini-review will cover the bioenergy sector, which is currently being heavily debated by various sides. Wood is being increasingly used for heat production in many areas of Europe (Kuba et al., 2008). Energy crops like maize, rapeseed or sugar beet have long been in focus for the production of biodiesel or bioethanol. However, the ethical debate is very controversial, in particular concerning the increasing competition between the food and energy sector for valuable cropland (Leopoldina, 2012).

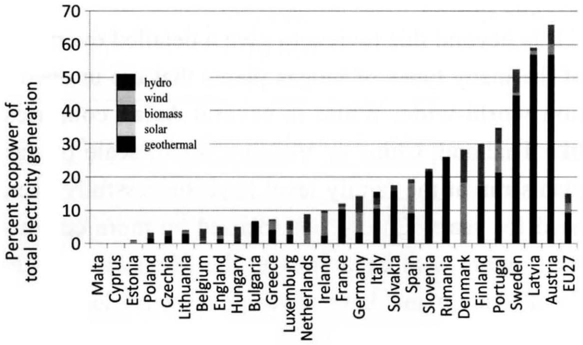

Figure 1. Percentage of ecopower technologies of the total electricity production in Europe.

Table 1. Selected sources of wastes as substrates for biogas production.
[1]http://www.biogas-renewable-energy.info; [2]Goberna et al., 2010;
[3]http://webapp.uibk.ac.at/biogas/results

Sector	Type of waste (fresh matter)	Methane potential [$m^3\ t^{-1}$]
Agriculture	Liquid cattle manure	20[1]
	Potato pulps	50[1]
	Brewery waste	75[1]
	Lawn cuttings	125[1]
	Corn residues	150[1]
	Olive mill residues (6%VOC)	200[2]
Industry	Bread residues, cereal waste	300[1]
	Slaughterhouse wastes	180[1]
	Molasses	230[1]
Municipal	Biowaste (source-separated) (40% dm)	170[3]
	Used grease (95% dm)	800[3]

During the last few years, energy and greenhouse gas (GHG) balance analyses have shown that the savings achieved using energy crops compared to fossil fuels were disappointing, and some studies have even shown a negative greenhouse gas balance of biomass-based fuels. Biogas production from energy crops - it should rather be termed agrogas - became more and more popular for various reasons: huge subsidies of feed-in tariffs for electricity, and a better GHG balance than for biodiesel and bioethanol. However, recent life cycle analyses have shown that agrogas production is not at all as positive as had been hoped for. Thus, the only bioenergy option remaining is biogas production from wastes, be they of agricultural or domestic origin (Leopoldina, 2012).

Sources of wastes and their biogas potential

Biogas, or biomethane, may be produced from many sources of waste. In Table 1, a snapshot of possible sources is given.

Biogas plants

It is beyond this review to give a detailed overview of the many types of biogas plants that are in operation world-wide. While in several Asian countries like Thailand, China or Vietnam, small scale biogas plants run at the family level have successfully been used for years, Europe has focused on more centralized plants with capacities in the Megawatt range. Small scale plants have always been regarded as not financially viable. However, recent political measures, for example in Germany, are advocating such small scale solutions. Up to 28 Euro-cents are offered as a feed-in tariff to small scale biogas plant operators that only use animal wastes. Insam and Wett (2008) have shown how small-scale biogas plants could contribute to a reduction of greenhouse gas emissions. A program in the German state of Bavaria (approx. 10 million inhabitants) aims at constructing 6000 small scale farm-based biogas plants that will have the capacity to replace 2 nuclear power plants within the next few years.

Research

Until a few years ago research and development on biogas production was mainly driven by engineers. Control of biogas plants is primarily accomplished by quantifying the methane production. In the past, the microbiology of biogas plants was not considered important for process optimization although the process is largely driven by microorganisms (Figure 2). However, with the availability of novel methodological approaches based on molecular biology, this has changed during the past five years.

One example is syntrophic acetate oxidation (SAO) by *Clostridium* sp., *Syntrophaceticus schinkii*, *Tepidanaerobacter acetatoxydans* (Westerholm et al., 2010, 2011) and other bacteria followed by the subsequent conversion of H_2 to methane by hydrogenotrophic methanogens (Fig. 2, bottom). This pathway is reportedly favored by high temperatures (55°C) (Zinder and Koch, 1984) and by low H_2 partial pressure (2.6 - 74 Pa, according to Hattori, 2008). Foremost, the presence of high concentrations of inhibiting ammonia, acetate or salinity (Sasaki et al., 2011; Schnurer and Nordberg, 2008; Westerholm et

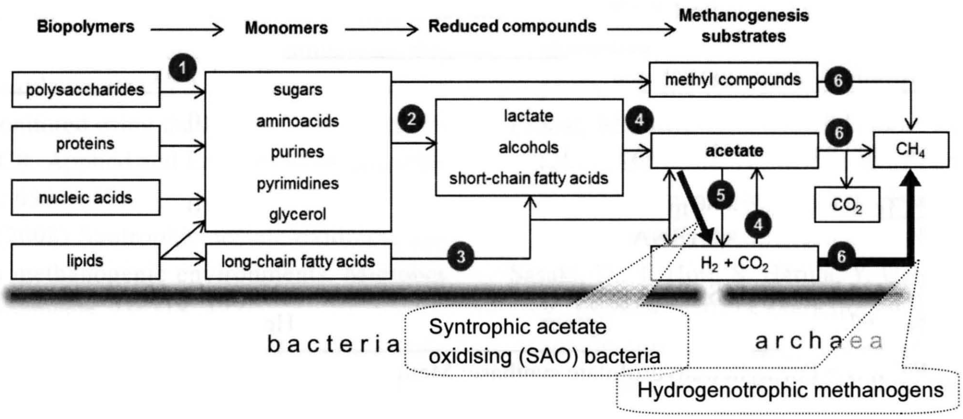

Figure 2. From complex compounds to methane (Insam et al., 2010, modified from Sousa, 2006); broad arrows: syntrophic acetate oxidation and subsequent hydrogenotrophic methanogenesis.

al., 2011) favors the SAO pathway. Methanogens of the genus *Methanosarcina* are able to rapidly adapt to increasing inhibitor concentrations since they are able to shift from the acetotrophic to the hydrogenotrophic pathway (Wang et al. 2011). A comparison of tolerance levels between *Methanosaeta* and *Methanosarcina* is given in Table 2, supporting the hypothesis that *Methanosarcina* is the workhorse in biomethanisation (Willy Verstraete, pers. comm.), a view that has been corroborated by Walter et al. (2012). Such knowledge not only confirms practical recommendations that are based on engineering experience (Laaber et al., 2007; Table 3), but this new understanding paves the way for process improvements.

Methods to analyse microbial communities

Classical isolation and cultivation techniques are laborious for anaerobic microorganisms, and particularly for archaea. The main reason is the long generation time and the specific requirements concerning oxygen partial pressure. For this reason, molecular tools have become popular for investigating microbial community dynamics in anaerobic digester environments. Such molecular tools include PCR-DGGE with follow-up sequencing, phylogenetic and functional microarrays (e.g., ANAEROCHIP and BACCHIP; Franke-Whittle 2009) and metagenome sequencing (e.g., Wirth et al. 2012). From such knowledge on the involved microbiota, benchmarks

Table 2. Characteristics of *Methanosaeta* and *Methanosarcina* (modified after De Vrieze et al., 2012, Fotidis et al. 2013).

Parameter	*Methanosaeta*	*Methanosarcina*
μ_{max} (d^{-1})	0.20	0.60
K_s (mg acetate/L)	10 - 50	200 - 280
Temp. range (°C)	7 - 65	1 - 70
Acetate (mg/L)	< 3 000	< 15 000
NH_4^+ (mg/L)	< 3 000	< 7 000
Na^+ (mg/L)	< 10 000	< 18 000
pH-range	6.5 - 8.5	5 - 8

Table 3. Evaluation scheme for biogas plants used in Austria (Laaber et al., 2007, abbr.).

Parameter	Range of values		
	Green (safe)	yellow (caution)	red (avoid)
pH	7.5-8.1	7.1-7.5	<7.1; >8.2
Total volatile fatty acids	< 1500	1500-4500	>4500
Acetic acid	<1000	1000-3000	>3000
Propionic acid	<250	250-1000	>1000
Butyric acid	<50	50-100	>100
Valerianic acid	<50	50-100	>100
NH_4-N (mg/L)	<5000	>5000	-
TS	4-8	<4; 8-9	>9

Table 4. Microbiological evaluation scheme for biomethanisation processes (De Vrieze et al. 2012).

Advanced evaluation scheme	Benchmark
% Total SAO FTHFS genes % Total bacteria 16S rRNA genes	≥ 10
% Total methanogens mcrA genes % Total bacteria 16S rRNA genes	≥ 10
% Methanosaeta16S rRNA genes % Methanosarcina 16S rRNA genes	Normal ≥ 10 Heavy duty ≥ 1

FTHFS = Formyltetrahydrofolate synthase; Methyl-coenzyme reductase

related to community composition and involved enzymes were established (De Vrieze et al. 2012; Table 4). These approaches need to be elaborated further in the future.

Outlook

Biomethane production from wastes is one of many options for the microbiologist to make use of an otherwise wasted resource. In Europe, and elsewhere, various approaches or combinations of approaches are being elaborated and tested, a few of them are named below:

- Methanogenic degradation of polycyclic aromatic hydrocarbons and other xenobiotics (Mogensen et al., 2003)
- Hydrogen producing bacteria (Bagi et al., 2007)
- *Syntrophomonas zehnderi* for oleate degradation (Palatsi et al., 2012)
- Long chain fatty acid degradation (Cirne et al., 2006)
- Genetically modified *Methanosarcina* (Lessner et al., 2010)
- Constructed ligno-cellulolytic cultures (Methanos®)
- Anaerobic cellulolytic fungi (Leis, 2013)
- Lactic acid production from biowaste (Probst et al., 2013)
- Bio-electrical systems (Logan et al., 2006)

Anaerobic digestion is currently driven by subsidies, this will change if processes are optimized and intermediate by-products are utilized. Life-cycle analysis tells that biomethane is at the forefront of the bioenergy sources. The involved microbiome needs to be further optimized, along with technical improvements. Altogether biogas from organic waste will have a bright future in the European and worldwide renewable energy context.

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